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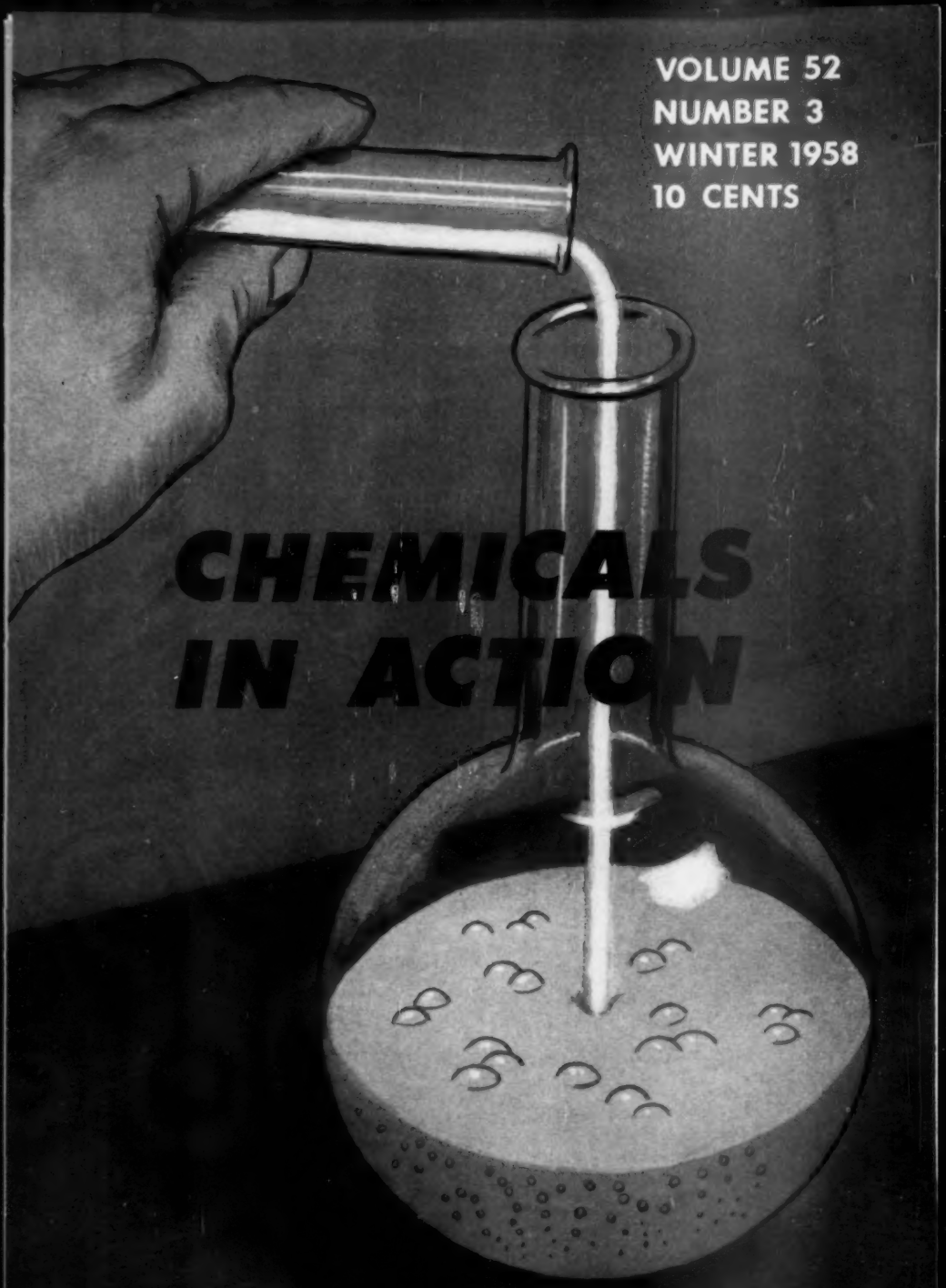

CHEMICALS IN ACTION

CORNELL SCIENCE LEAFLET

CHEMICALS IN ACTION

by VERNE N. ROCKCASTLE

If you use a magnifier to examine a pinch of table salt, what do you see? Little cubes? What color are they? Try cutting each cube in two. Do the pieces still taste like salt? If you could cut these bits of salt into smaller and smaller bits, you would soon need a microscope to see them. But they would still be salt. There would come a time, however, when these tiny pieces would be too small to be seen, even with a microscope—so small that they could not be cut and still be salt. The smallest bit of salt that could still look and taste like salt is a *molecule*. Most objects around you are made of billions of molecules. A little cube of salt from a salt shaker has billions of salt molecules in it, plus a lot of space around each molecule.

If it were possible to cut a molecule into pieces, you would find that it is made of *atoms*. More than 100 different kinds of atoms are known. Gold is formed from one kind of atom. Iron, tin, silver, mercury, sulfur, oxygen and hydrogen are formed from other kinds of atoms. So are uranium 238, neptunium, plutonium, helium, phosphorous, chlorine and sodium. Atoms themselves are made of many smaller particles, and scientists are eagerly seeking to learn more about these particles and how they form atoms and molecules.

Most materials about you are combinations of several kinds of atoms. Ordinary salt, for example, is formed from two kinds of atoms, sodium and chlorine. When the two of them join, the combination is called *sodium chloride*. That is what a chemist calls table salt. If you looked on a chemist's shelves and saw a bottle labelled "sodium chloride", you would know that it could be safely sprinkled on meat and potatoes because you have done it. The table salt you use, however, is not so pure as the sodium chloride on the chemist's shelves.

A drop of water is wet. Yet water is a combination of two kinds of atoms—hydrogen and oxygen. Hydrogen and oxygen alone are gases, but when their atoms join together in the proper manner, they form water. Such is the magic of chemicals.

Everything you can see and touch is made of chemicals. Some chemicals join to make food. In factories some chemicals are mixed to make plastics. Others

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there are billions of tiny spaces between the molecules in a glass of water. Into these spaces go the molecules of some of the chemicals that you put into water. A chemical that dissolves in water is called a *solute*. Salt, sugar and baking soda are solutes when they dissolve in water. The water that dissolves the chemicals is called a *solvent*. Water is a solvent for many things.

Many factors determine how quickly water will dissolve chemicals, and how much of the chemical will dissolve. Fill one cup with cold water, and another with very hot water. Add sugar, a teaspoonful at a time, to the cold water, stirring constantly, until some undissolved sugar remains in the bottom of the cup. How many teaspoonfuls of sugar were you able to dissolve in the cold water?

Now add sugar, a teaspoonful at a time, to the cup of hot water. Record the number of teaspoonfuls you can add before undissolved sugar can be seen in the bottom of the cup. Which dissolved more sugar—hot water or cold water?

Fill a cup with hot water and dissolve as much sugar as you can in it. Can you see the dissolved sugar? When you can dissolve no more sugar, set the cup in a refrigerator until it is cold. Remove it and examine the contents. Can you see any sugar in the cup? What would happen to the visible sugar if you reheated the contents of the cup? What would happen if it cooled again?

Try the same experiment with salt instead of sugar. Can you dissolve more salt in hot water or in cold water? Can you dissolve as much salt as sugar in either hot or cold water? Not all chemicals dissolve equally well in water.

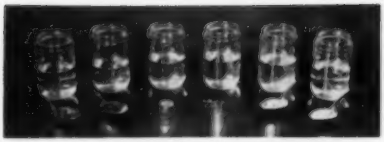
Sugar and salt both dissolved in water, but oil did not. It remains on top of the water because it is lighter than water. Water does not dissolve oily or greasy substances. There is a way to make grease flow away in water, however. To a half-glass of water add a teaspoonful of oil such as salad oil. After stirring these two liquids, examine the glass to see if they mixed. Now add a teaspoonful of detergent or soap flakes. Stir the mixture slowly so that suds do not hide the reaction. Can you see that the oil now spreads through the water in tiny droplets? Detergents and soaps *emulsify* grease and oil. That means that they help to break grease into tiny droplets that do not stick to each other. Then the water can wash the grease away.

are heated together and rolled into sheets that we call glass, or steel, or paper. Some chemicals are joined together in a complex mass to make YOU!

In this Leaflet you will learn what happens when certain chemicals are mixed together. Sometimes nothing happens. Other times there is a *reaction*. This means that the chemicals become changed. Sometimes a chemical reaction makes the mixture warm, or even hot. Sometimes a chemical reaction makes the mixture cooler. Sometimes bubbles of a gas are produced. Sometimes two liquids, when mixed, form some milky stuff that settles to the bottom of the container without dissolving. Sometimes two colored liquids, when mixed, become a different color, or colorless. As you play with chemicals, you will learn about many interesting reactions or changes that take place when they are mixed.

WATER

One of the most common chemicals on earth, and one of the most important to us, is *water*. Water is important because it can dissolve so many materials. You can see this for yourself by trying to dissolve some common kitchen chemicals in water. Set several glasses in a sink and fill each about half-full with water. To each container add a half-teaspoonful of one of the following:



Which of the materials will disappear when added to a jar of water?

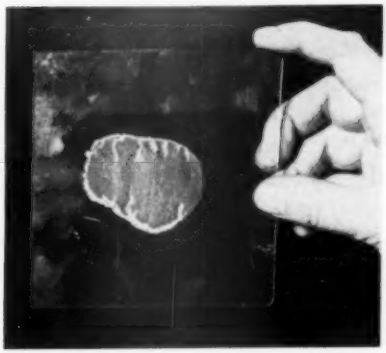
sugar
salt
baking soda
rubbing alcohol
olive oil
vinegar
scouring powder
a penny
carpet tacks

Stir each with a drinking straw or a spoon, then let the glass stand overnight. In the morning examine the containers carefully. Can you see any sugar, salt or baking soda? Is there any alcohol, olive oil or vinegar visible? If any of these three liquids is visible, is it mixed through the water, is it on top of the water, or is the water on top of it? Which of the three liquids did not mix with the water? Is there any change in the penny, in the carpet tacks?

If the chemical that you add to water disappears, it dissolves. Although you cannot see them,

a drop of this salty water on a clean glass surface and let the water evaporate. Can you see anything left after the water has disappeared? Look at the *residue* (the stuff that is left) with a magnifier. What do you see? Compare this with table salt as seen under a magnifier. Let all the water in the cup evaporate. (This may take a few days; how can it be speeded?) What is left in the cup? How does the amount of this residue compare with the amount of salt that you added to the water when you started the activity?

Make a *saturated* solution of sugar by dissolving all the sugar you can in a glass of hot water. Hang a string from a pencil as shown so the string hangs in the saturated solution. Set the cup aside for a few days and let the water evaporate. What is left on the string? This is often called "rock candy." Can you see why? The rock candy is just sugar that has re-crystallized when the solvent (water) evaporated. Watch for other evidence that dissolved chemicals re-crystallize when their solvent evaporates.



A drop of salt water evaporated to leave this residue of tiny white salt cubes

On warm, clear summer nights some plants give off water from pores in the leaves. Droplets of shining water can often be seen around the edges of strawberry and clover leaves. This *water of guttation* contains some dissolved chemicals. Dew, on the other hand, is water that has condensed from the air around the plant. It does not contain chemicals, but is pure water. Do you know now how you can tell the difference between water of guttation and dew? Remember that when a solvent evaporates, it leaves the solute as a *residue*. When pure water evaporates, it leaves nothing behind. How can you determine whether a drop on a leaf margin is water of guttation or dew?

Water can dissolve gases as well as solids. Put some water in a sauce pan on the stove. Heat it until you see the very first bubbles forming on the bottom of the pan. Take the water temperature with a thermometer that

Rub a little butter, lard or oleomargarine on your hands and hold them under the faucet. Does water wash away the grease? Now soap your hands thoroughly, and see how easily the grease disappears. The soap emulsified the grease so that water could wash it away.

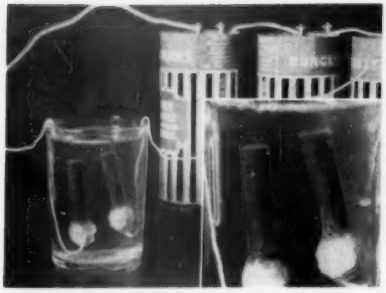
When water contains dissolved minerals such as calcium and magnesium, it is called "hard water." Soap helps to remove these minerals as well as to emulsify fats. The ring around the tub after a bath may not be all dirt. Much of it is the minerals the the soap helped to remove when it "softened" the water.

Some of the foods in your kitchen contain fats that have been emulsified so they no longer stick together in gobs, but are distributed evenly throughout the liquid. Milk is an *emulsion*. Tiny particles of butterfat are distributed all through the water that makes up most of the milk. Mayonnaise is also an emulsion. Each of these liquids needed an emulsifying chemical to make the fat mix with water. In milk, a chemical called *casein* that is produced by the cow helps to emulsify the butterfat. In mayonnaise, egg yolk is beaten into a mixture of oil and vinegar to emulsify the oil. Can you find other emulsions in your kitchen?

Since water easily dissolves many chemicals, it acts as a carrier for these chemicals. If you put a teaspoon of sugar on a piece of paper toweling, or on a handkerchief, it will not go through the paper or cloth. But if you first dissolve the sugar in water, you can then pour it through the handkerchief, or let it soak through the paper. When sugar is dissolved, it divides into separate molecules, and these can pass through almost anything that water can.

Water helps to carry chemicals into plants, and into our bodies. In the soil, water dissolves many chemicals necessary for plant growth. The water, with its dissolved chemicals, enters the roots of the plant and continues up the stem to all the cells. In the leaves, much of the water evaporates, leaving the chemicals that it dissolved in the soil. More rain falls on the soil, more chemicals are dissolved and make their way into the plants, where they are left when the water evaporates.

Even though such solutes as salt and sugar are distributed throughout the solvent, they do not become a part of the water itself. You can see that they remain behind even though the water evaporates. Put a half-teaspoonful of salt in a cup of water and stir it until it dissolves. Put



The inset shows tiny bubbles of hydrogen (right) and oxygen (left) forming along the carbon rods

"Sani-Flush," and other similar household drain-cleaners. Stir the water until the sodium hydroxide has dissolved.

Now connect the exposed ends of the wires to two dry cells as shown above. (Are the cells in the picture connected in series or in parallel?) What do you observe taking place at the carbon rods? Do bubbles form at the same rate at both rods? Do the bubbles rise at the same rate at both rods?

The gas that forms in greater amount is *hydrogen*—the lightest gas known. The other gas is *oxygen*. These two gases were water before you passed an electric current through the water to break up its molecules. Chemists learned long ago that when water breaks down it forms twice as much hydrogen as oxygen. To express the ratio of hydrogen to oxygen, chemists write the *formula* for water as follows: H_2O. They call it "H-two-O." This means that there are two parts of hydrogen (H) to one part of oxygen (O).

Perhaps you can figure out a way to collect some of these bubbles in a vial, a toothbrush container, or a test-tube. (Hint: Fill a vial with some of the sodium hydroxide solution and invert it over a carbon rod. Try to keep most of the carbon rod below the mouth of the vial so that the vial does not interfere with the flow of electricity through the solution.)

Hydrogen gas is explosive. You can make a harmless miniature explosion, however. After you collect a vial full of hydrogen, remove the vial, but keep the open end *down*. Hydrogen is so light that it will remain in the vial while it is inverted. Light a match and bring it near the mouth of the vial. Can you hear a small "pop" or a "whoosh?" Do not try this with a larger amount of hydrogen, or you may be sorry! Now cork up a vial that has filled with ogygen. Light one end of a thin wooden stick. As soon as it burns well, blow out the flame, remove the cork from the test-tube, and quickly insert the glowing end of the stick. Does it glow more brightly, or even burst into flame? Oxygen helped it burn.

When a container of cold water warms, some of its dissolved air forms tiny bubbles along the side

will measure to 212°F. (the boiling point of water at sea level). Is the water boiling? The bubbles you see are not steam, but *air*. The dissolved air in the water forms bubbles as the water is heated. Set a glass of cold tap water in the sun to warm. Do bubbles of air form around the glass? Warm water cannot hold as much air as cold water. This is part of the reason why active fish such as trout live in cold water. Warm water does not contain enough oxygen for them.

Water = Hydrogen + Oxygen

Water is composed of hydrogen and oxygen. Normally, these two elements are gases, but in combination we know them as water (or steam, or ice). If you pass an electric current from dry cells through water, you can watch hydrogen and oxygen bubbles form as the electricity helps to break up the water molecules.

Remove the metal covers from two worn-out flashlight cells, but do not discard them. They can be used for later experiments. Running through the center of each cell, inside the black paste, is a carbon rod with a brass cap. Remove the rods by scraping away the black stuff. Using pliers, carefully loosen the brass caps. Clean the rods thoroughly. Now scrape bare the ends of two 18-inch pieces of insulated wire. Tape the end of each wire tightly to one end of each carbon rod. Light a candle and drip some wax over the connections until they are water-tight. Be careful not to get wax on the exposed half of the rod. Remove one inch of insulation from the other end of the wires.

When your carbon rods and their connections are complete, set them in a glass of water. Add a quarter-teaspoonful of *sodium hydroxide* to the water. *Caution:* Do not pick up the sodium hydroxide in your fingers. Sodium hydroxide, often called *lye*, is a strong chemical that can injure your skin. It is used in "Drano."

Hydrochloric acid and *nitric acid* are two other common strong acids. They are used in industry and in laboratories to make many other chemicals.

Vinegar (called *acetic acid* by chemists) is a weak acid. It produces fewer hydronium ions than sulfuric acid or hydrochloric acid. The *citric acid* in lemon juice and grapefruit juice, and the *lactic acid* in sour milk are weak acids. They will not "eat" holes in clothing as sulfuric acid can. *Carbonic acid* is a weak acid that gives carbonated water its tangy taste. It is formed when carbon dioxide dissolves in water.

Acids can change the color of certain chemicals known as *indicators*. Beet juice, cherry juice, grape juice, and red cabbage juice act as acid indicators. To a half-glass of water add a teaspoon of one of these juices. Stir it well. Can you see that the water has a reddish-purple color? Now add a half-teaspoon of vinegar or lemon juice and stir again. Does the water change color?

Chemists use very sensitive indicators to tell them when a solution is acid. Some indicators are so sensitive that their color will change from blue to pink when the tiniest bit of acid is present. *Litmus paper* is a paper that has been soaked in an indicator and dried. It turns reddish when dipped into acids.

Get a few pieces of red and a few of blue litmus paper from your drug store, or from the high-school chemistry teacher. Dip a piece of red litmus paper into water containing a few drops of vinegar. What happens? Now dip a piece of blue litmus into the same solution. Is there any difference? Use fresh litmus paper to test each of the following solutions: lemon juice, sour milk and ammonia water. (Which of the three are acids?)

Some metals react strongly with acids to produce bubbles of hydrogen gas. Thoroughly wash the zinc case that you removed from the outside of the worn-out flashlight cell. Use tin shears or old scissors to cut it into bits. Drop a few of these bits into a quarter-glass of vinegar. Can you see anything happening after it has stood for ten minutes? The bubbles are the same as one of the gases produced when you sent an electric current through water. The gas is hydrogen.

Get a little dilute hydrochloric acid from the drug store or from the high school chemistry teacher. Pour a little into a glass and add a few bits of zinc. Do bubbles form faster when zinc is added to vinegar or to hydro-

Both hydrogen and oxygen are commercially important. Tanks of the compressed gases supply oxy-hydrogen blowtorches that produce a flame that can melt steel. Hydrogen is added to liquid vegetable fats to make "shortening" such as "Crisco" and "Spry" that your mother may use to make piecrust. Hydrogen is used to remove the oxygen from some valuable ores. Copper is often mined as an ore in which the copper is combined with oxygen. Hydrogen helps to remove the oxygen, leaving pure copper. (What is formed when the hydrogen combines with the oxygen?) How many other uses of hydrogen can you find?

Oxygen helps keep you alive. About 20% of the air you breathe is oxygen. Sometimes there is not enough oxygen in the air for a very sick person. Then he is allowed to breathe "bottled" oxygen—oxygen that may have been collected by passing an electric current through water as you did. Pilots must add oxygen to the air they breathe when they fly at high altitudes. Liquid oxygen is used for both fueling and cooling giant rockets.

When fuels such as gasoline burn, they need oxygen. Gasoline is a chemical containing hydrogen and carbon. When its hydrogen burns, water is formed. You can sometimes see it drip from an exhaust pipe, or it may form a cloud of "steam" on a cold morning. When the carbon burns, it forms *carbon dioxide* if there is plenty of oxygen, or *carbon monoxide*, if there is little oxygen. Carbon monoxide is poisonous. For that reason, it is unsafe to stay in a closed garage where an auto engine is running, unless a hose takes the exhaust gases outside.

ACIDS, BASES AND SALTS

Acids

Vinegar is one of a large group of chemicals called *acids*. The battery in your car contains acid. Lemon juice and grapefruit juice contain acid. Acids usually taste sour. Strong acids can eat holes in clothing, but they are also useful in many ways.

All acids contain hydrogen. When acids are dissolved in water, the hydrogen in the acid combines with water molecules to form charged particles called *hydronium ions*. Strong acids produce many hydronium ions. Weak acids produce fewer hydronium ions.

Sulfuric acid is the strong acid used in car batteries. If you should spill in on your clothing, it might "eat" holes in the cloth.

When Diane inverts her extinguisher, a jet of water squirts from the nozzle

The soda-acid fire extinguishers in your school do not use vinegar. Most of them use hydrochloric acid. The rest of the extinguisher is similar to yours. Try your fire extinguisher again, using citric acid powder in place of the vinegar. Is the result the same? (Citric acid can be purchased at many grocery and drug stores.)

Acids have many important industrial uses. Hydrochloric acid is used to make *ammonium chloride*, one of the chemicals in flashlight cells. Hydrochloric acid (written *HCl* and called "H-C-L" by chemists) helps to clean metals before they are painted or soldered. It is used in making *silver chloride*, the light-sensitive chemical in photographic film. How many other uses of HCl can you find?

Sulfuric acid (written H_2SO_4 and called "H-two-S-O-four" by chemists) is perhaps the most important of all acids. It is used to make other acids, textiles, explosives, and fertilizer, and in the extraction of many metals from their ores. Sulfuric acid is used in most car batteries. Can you learn of other uses of H_2SO_4?

Bases

When you tested vinegar, lemon juice and ammonia water with litmus paper, you found that ammonia water did not turn blue litmus red. Instead, it turned red litmus *blue*. Ammonia water is a *base*. Bases form *hydroxyl* ions in water. These ions contain both hydrogen and oxygen, but not in the same proportion as in water. Remember that water has two hydrogen atoms for each oxygen atom. A hydroxyl ion has only one hydrogen atom for each oxygen atom. A hydroxyl ion is written OH^-. Two common bases that produce these ions are:

Lye	(Sodium hydroxide)	NaOH
Ammonia water	(Ammonium hydroxide)	NH_4OH

chloric acid? Which is the stronger acid? Try some other metals in the acid. Do they all react in the same way?

Acids sometimes produce other gases besides hydrogen. If baking soda is added to water and vinegar, it fizzes quickly. These bubbles are *carbon dioxide* gas —the same gas that is in the air that you exhale, and the same gas that makes the bubbles in carbonated water.

To a half-glass of water add a teaspoonful of vinegar, and stir it well. Now add a teaspoonful of *baking soda (sodium bicarbonate)* to the diluted vinegar. What happens? Add a teaspoonful of sodium bicarbonate (baking soda) to a fresh half-glass of water. Stir it until the soda is dissolved. Now add a teaspoonful of vinegar and stir it. Is the reaction the same as before? Does it make any difference whether the soda is added first or last?

Carbon dioxide under pressure squirts water from many fire extinguishers. To see how a simple *soda-acid fire extinguisher* works, fill a pint bottle about three-quarters full of water. Add three teaspoons of baking soda and stir it well. Tie a thread around the mouth of a small vial and fill the vial with vinegar. Carefully push a piece of glass or metal tubing into a one-holed stopper that just fits the mouth of the pint bottle. Suspend the vial of vinegar in the soda water so the mouth of the vial is *above* the water level. Place the stopper tightly in the pint bottle to hold the thread of the vial.

In this fire extinguisher, the acid vial hangs with its mouth above the soda water—until you tip it

To use your soda-acid fire extinguisher, turn the bottle upside down to let the vinegar in the vial mix with the soda water. What happens to the soda water as carbon dioxide gas is formed inside the bottle? Does pure water squirt out?

Can you see that each has the word hydroxide in its name? Each has "OH" in it, too.

Sodium hydroxide is a strong base. It helps dissolve animal tissues, including fat. It is also used to make soap, paper, textiles and plastics. Its ability to dissolve fats and greases makes it useful in opening clogged drains. Remember, however, that unless sodium hydroxide is diluted with plenty of water it can be very harmful to your own body!

Ammonia water can dissolve grease, too, even though it is weaker than sodium hydroxide. Ammonia gas escapes readily from the water once it is exposed to the air. For that reason, ammonium hydroxide (ammonia water) is safe to use for cleaning household items. When all the ammonia gas has left the solution, it is no longer a base. What can you learn about other common bases?

Salts

Many chemicals that are neither acids nor bases are *salts*. When a chemist uses the word "salt," he rarely means table salt. He usually means a group of chemicals that form when an acid and a base are mixed together, or when a metal reacts with an acid.

When zinc is added to hydrochloric acid, *zinc chloride* is formed. It is a salt. When copper is added to strong sulfuric acid, *copper sulfate* is formed. It is a salt that is bright bluish-green in color. Many salts are poisonous, but some are common kitchen chemicals: sodium bicarbonate, cream of tartar, milk of magnesia, borax, baking powder. Not all salts are formed by an acid and a base being mixed, or by a metal being added to an acid. Some salts such as table salt and borax are found as salts in nature.

Get a few crystals of copper sulfate from a drug store or from a chemist. Dissolve them in a half-glass of water until the water is bluish-green in color. Place a large clean nail in this solution for several minutes, then remove it. What happened to the nail?

The left end of this nail was copper coated by the copper sulfate solution

Let it dry before you wipe it. Can you see a copper coating on the nail where it was in the copper sulfate solution? Now try a strip of zinc. Does it get a coating of copper? A silver spoon? When an iron nail is placed in copper sulfate solution, the iron in the nail combines with the "sulfate" better than copper does. Iron replaces the copper in solution, forcing the copper to be deposited on the nail. Iron, zinc, magnesium and aluminum all combine with the sulfate more easily than copper does. Silver and gold are less *active* than copper, so they will not replace copper. It is just as if iron were chemically stronger than copper, and zinc were chemically stronger than iron. Silver and gold, however, are chemically weak. They will react with few chemicals. Knowing the chemical activity of various metals helps chemists to tell what some reactions will be before they try them.

CHEMICAL CONDUCTORS

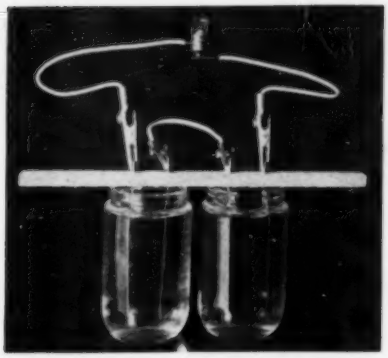
On page 9 you learned that an electric current can be passed through water in which sodium hydroxide is dissolved. Many chemicals, when dissolved in water, can conduct an electric current. To test some of these for yourself, arrange two wires, a 1-cell flashlight bulb, and three dry cells (or flashlight cells) in series. Cut in two one of the wires from the bulb. Scrape away the insulation for two inches from each cut end. Put the two bared wires in a glass and fill the glass with water. Does the bulb light? Bring the wires close together but not touching. Does the bulb light?

Add a half-teaspoonful of table salt to the water, stir it, and try the bulb again. Does it light now? Add more salt. Is there any change? Bring the wires close together, then farther apart. How does this affect the brightness of the bulb? Chemicals that conduct electricity when they are dissolved in water are called *electrolytes*. Try some other kitchen chemicals in place of salt. Is sugar an electrolyte? vinegar? baking soda? sodium hydroxide?

It takes only a tiny bit of an electrolyte to carry an electric current. For that reason, it is dangerous to work around electrical appliances when your hands are wet. The trace of salt on your skin (where does the salt on your skin come from?), or the chemicals dissolved in the tap water that wets your hands, might be dangerously conductive.

Corrosion

On page 16 are shown two *wet cells*. Each has in it a copper and a zinc strip. (The zinc strip came



These wet cells have a zinc strip (left) and a copper strip (right) immersed in dilute acid

from a worn-out flashlight cell.) The copper strip of one cell is connected to the zinc strip of the other cell. When dilute HCl (hydrochloric acid, remember?) is used in the cells, the electric current between the remaining metals may be strong enough to light a tiny bulb for a short time. Many dissolved salts will also produce a small current when two unlike metals are present. When electricity flows in such a cell, however, the metal strips are slowly destroyed. Chemical action that destroys the usefulness of a metal is called *corrosion*.

Many metal objects such as tin cans, iron pipes, and auto bodies quickly corrode if not protected from air and water, especially when salt is present. Can you find places on your family car where corrosion is taking place? Can you suggest ways of preventing corrosion, or stopping it once it has started?

THE CHEMIST AND YOU

Plastics, television sets, toothpaste, medicines, antifreeze, fertilizer, fuel for both cars and homes, photographs, home permanents and foods are only a few of the many products that chemistry has developed. In all major industries professional chemists work in modern laboratories and are well paid for their efforts.

You, too, can be a chemist—right in your home or at school. If you are careful, use only small amounts of each chemical, and clean up thoroughly after each experiment, you can learn much about common chemicals. A white enamelled dishpan makes a good laboratory sink in which to work. Wash all your apparatus in clean water after each experiment. Keep a record of your observations just as a professional chemist does. You will find that it is fun and fascinating to watch chemicals in action!

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